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Experimental Studies of Heat Exchangers for Diesel Generator

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Abstract - The heat exchangers play a big role in industrial application, their efficiency is an essential target for the users. Four shell and tube heat exchangers are designed, built, and tested using diesel generator. The performance characteristics of heat exchangers have been investigated experimentally by analyzing heat transfer rate, overall heat transfer coefficient and effectiveness. The shell and the copper coil dimensions are identical in the four heat exchangers. The mass flow rate of oil was constant for all four-heat exchangers, 0.0207 Ib/s.

The results indicated that the heat transfer rate, overall heat transfer coefficient and effectiveness for all four heat exchangers increased with increasing diesel engine RPM. The heat exchanger with circular fins with ten holes (HE-2) showed the highest heat transfer rate and the effectiveness reached up to 32% using heat transfer rate and maximum heat transfer rate, however using number of transfer units and specific heat of oil and water the effectiveness reached 38%. However, the heat exchanger (HE-1) with small internal cylindrical fins on the surface of the coil has the lowest effectiveness 16%. In general, the location and size of fins affect on heat exchanger performance.

***Keywords*:** heat exchanger, heat transfer rate, effectiveness, number of transfer units

1. Introduction

Modern Heat exchangers were first brought to light in 1876, mainly used for the refrigeration of foods and items. These exchanges tend to be plate or parallel flow. Although the modern exchanger is very efficient and successful within many different industries across the world, there remains the question of can we get better. Previous studies showed that the optimization of a heat exchanger model by resolving common system concerns, efficiency, fouling, leakage, dead zones, and vibration. These issues are prevalent in the HVAC industry, which are critical to the under-performing heat exchangers. The heat exchanger was tested at only three different wind speeds (20, 40%, 60%) to take the temperature readings every 5 minutes to allow for maximal heat transfer. The efficiency of heat exchanger at the specified speeds was determined to be .7413 at 20%, .6463 at 40% and .6351 at 60%. [1]. In addition to resolving common heat exchanger problems the end goal is to improve the efficiency of the heat exchanger. R.L Webb et al. focused on [1] four design cases: (1) reduced heat exchanger material; (2) increased heat duty; (3) reduced log-mean temperature difference; and (4) reduced pumping power. The novel method was presented by B.Linnhoff et al. [2]. Previous work [3] showed that three rough tube applications are presented: 1. to obtain increased heat exchange capacity; 2. to reduce the friction power; and 3. to permit a reduction of heat-transfer surface area. El-sadi et al. designed and analyzed the micro screw concentric tube heat exchanger to determine the overall heat transfer coefficient and the amount of heat created by friction [4]. One of the most common styles of heat exchangers and what is on the diesel engine currently is a shell and tube heat exchanger. In a shell and tube heat exchanger, one of the liquids is passed through many narrow tubes, and the other is passed through a shell surrounding the tubes. In the tubes there are turbulators, which causes turbulent flow through the tubes. There are also baffles which "maximize the amount of thermal mixing that occurs between the shell-side fluid and the coolant pipes. The shell-side fluid must work its way around these baffles, which causes the flow to repeatedly pass over the tube bundle, thus transferring energy and exiting the heat exchanger at a lower temperature" [5]. Adrian [6] examined the coupling between losses due to heat transfer across the stream-to stream ΔT and losses caused by fluid friction using the concept of heat-exchanger irreversibility. The novel method was presented by B. Linnhoff et al. [7], the method is the first to combine sufficient simplicity to be used by hand with near certainty to identify "best" designs, even for large problems. "Best" designs feature the highest degree of energy recovery possible with a given number of capital items.

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2. Design Heat exchanger

Solid works was used to design different models of heat exchanger as shown in Figure 1. Table 1 shows the dimensions of the inner copper tube and clear polycarbonate shell.

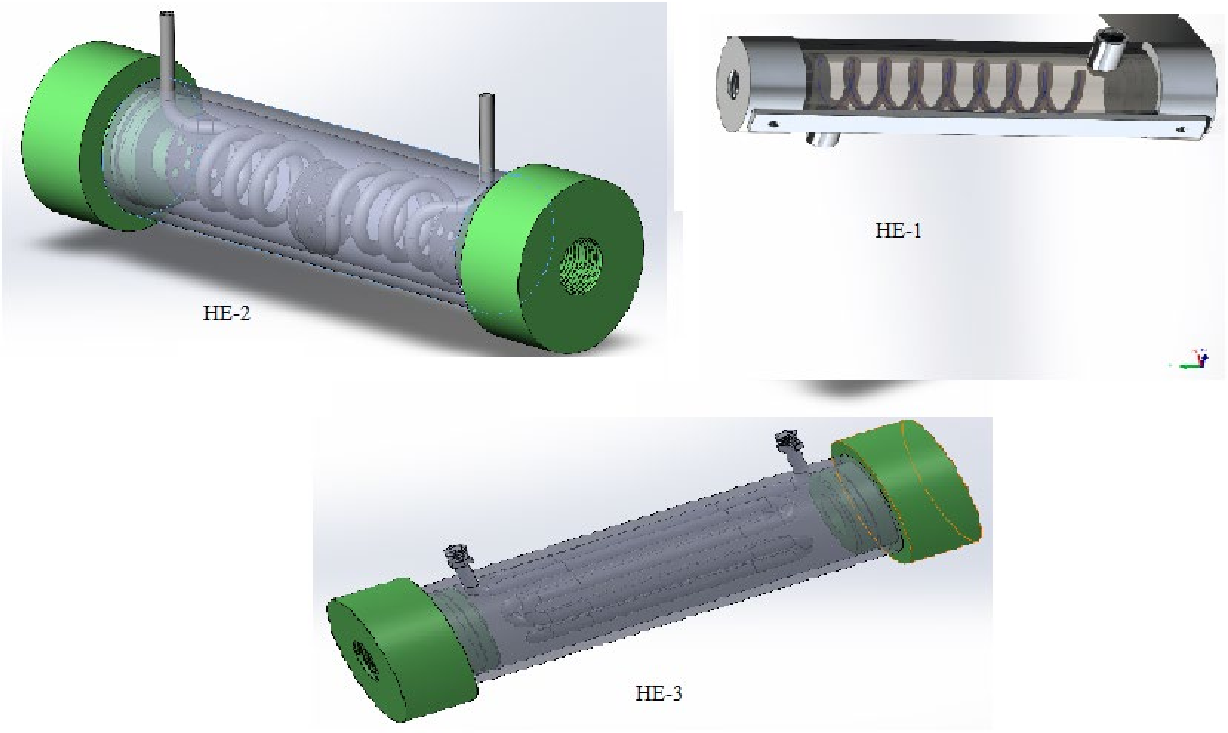

Fig 1. Examples of Different solid works models of heat exchanger

Table1. shows the length and diameter of copper tube

Heat exchanger model	Diameter of copper tube	Length of tube	Shell length (polycarbonate)
All heat exchangers	0.19 in	36 in	12 in

3. Manufacturing process and Material

The materials required for this project include aluminum stock, 6061 which is fabricated into everything such as pipe fittings, it is used to manufacture the caps of heat exchangers. It is strong and corrosion resistant, and it is easy to machine and weld. Model # TRAX 1630 CNC lathe was used to manufacture aluminum caps and fins.

Clear polycarbonate plastic, which is high pressure hard plastic tubing for air and water was used for the shell of heat exchanger. Also, copper tube was used as well as various fittings and adapters.

The first issue arose between the fitting and the polycarbonate shell was the leaking, it was solved by using JB Weld around the seam between the two. More leaks occurred between the fitting and the adapter for the oil. This was also fixed using multiple coats of JB Weld. The pair of adapters were manufactured using CNC machine and used for each of the heat exchangers. Metal strapping was added to the end caps to have a mechanical way of keeping them together, aside from the compression of the o-rings against the shell. The length and diameter of the copper tube were consistent for all four heat exchangers as well as the clear polycarbonate shell.

Figure 2 shows the simple heat exchanger (HE-1) which consist of copper tube and clear polycarbonate shell, however however for the second heat exchanger (HE-2) three circular fins with ten holes were added before the copper coil in clear clear polycarbonate shell as shown in Figure 3. Heat exchanger (HE-3) includes one raw with 5 tubes and clear polycarbonate polycarbonate shell as shown in figure 4. Cylindrical fins with diameter-----and length ----were added on the surface of the the copper coil tube for the fourth heat exchanger (HE-4) is shown in figure 5.

Fig. 2. Heat exchanger HE-1

Figure 3. Heat exchanger HE-2

Fig. 4. Heat exchanger HE-3

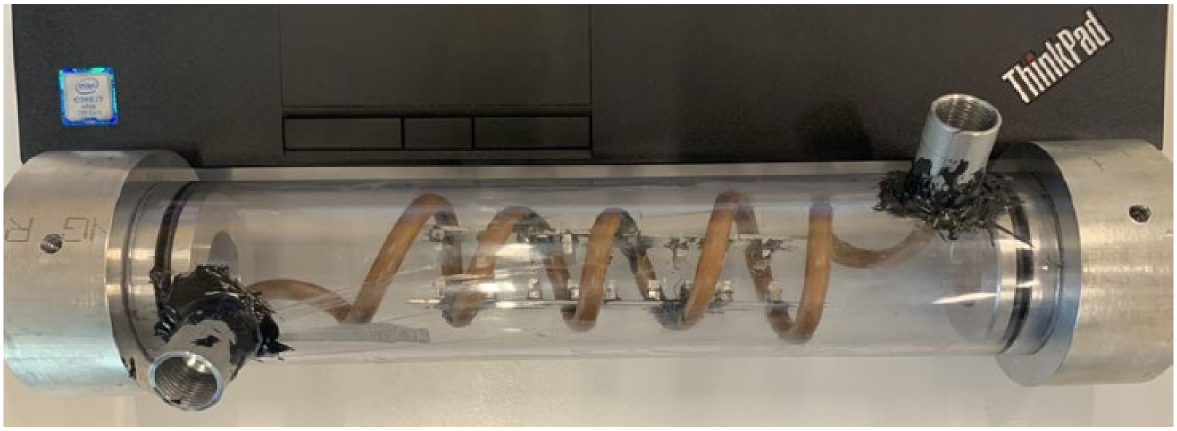

Fig. 5. Heat Exchanger HE-4

3. Testing Heat Exchanger

The Ford turbocharged diesel engine-generator set is a unit that is designed to produce electrical energy for supply at peak power demands and to power devices requiring sufficient power to drive equipment. The engine is a four-cylinder internal combustion engine working on the diesel cycle. In addition, a turbocharger is installed in the exhaust line to utilize the high-energy exhaust to drive a high-speed induction turbine to boost the inlet pressure to the engine. This pressure increase produces additional output of the engine particularly at higher loads and demands.

the analyses are based on the data collected from the turbocharged FORD diesel engine. The heat loss from the engine is transferred through a heat exchanger as one used in a common automobile. However rather than using air, this engine uses cold water from a storage tank in the power plant's basement, between the exhaust and the coolant system. The mechanical energy from the engine crank is transmitted to an electric generator unit, and the electricity generated is transferred to a load cell (resistance heater), which then transfers the heat generated to the cold water flowing back into the basement tank. The engine oil is cooled by the coolant when it is flowing in copper tube as shown in the below figure 6.

Fig. 6. testing one of the heat exchangers on the diesel engine

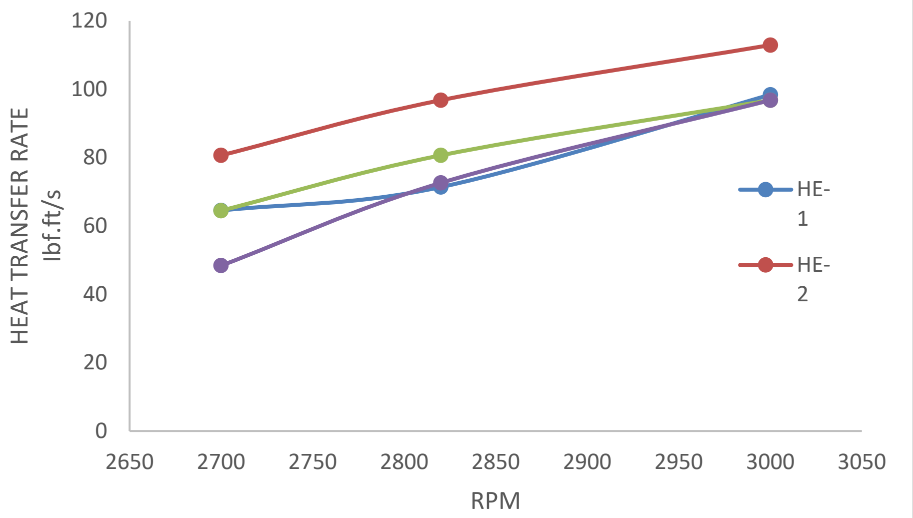

Fig. 7. Heat transfer rate vs. RPM

Heat transfer rate vs. RMP was carried out as shown in Figure 7. It shows that HE-2 has the highest heat transfer rate followed by HE-3, this is due the effect of fins shape and size. The results indicated that the heat transfer rate increased with increasing the RPM (revolutions per minute) for all heat exchangers.

Effectiveness was calculated using eq. 2 as shown in Figure 8 is increasing with increasing the RPM, it is noticed that HE-2 has the highest effectiveness and this is due to the circular fins with holes which increases the surface area of heat transfer and the location of fins are attached before the copper coil, however the copper tube is finned on the interior, HE-4, the size and location of fins affects on the performance of heat exchanger. HE-4 has the lowest effectiveness.

$$q_{max}=Coil\cdot(Toili-Twateri) \tag{1}$$

$$\varepsilon = q/q_{max} \tag{2}$$

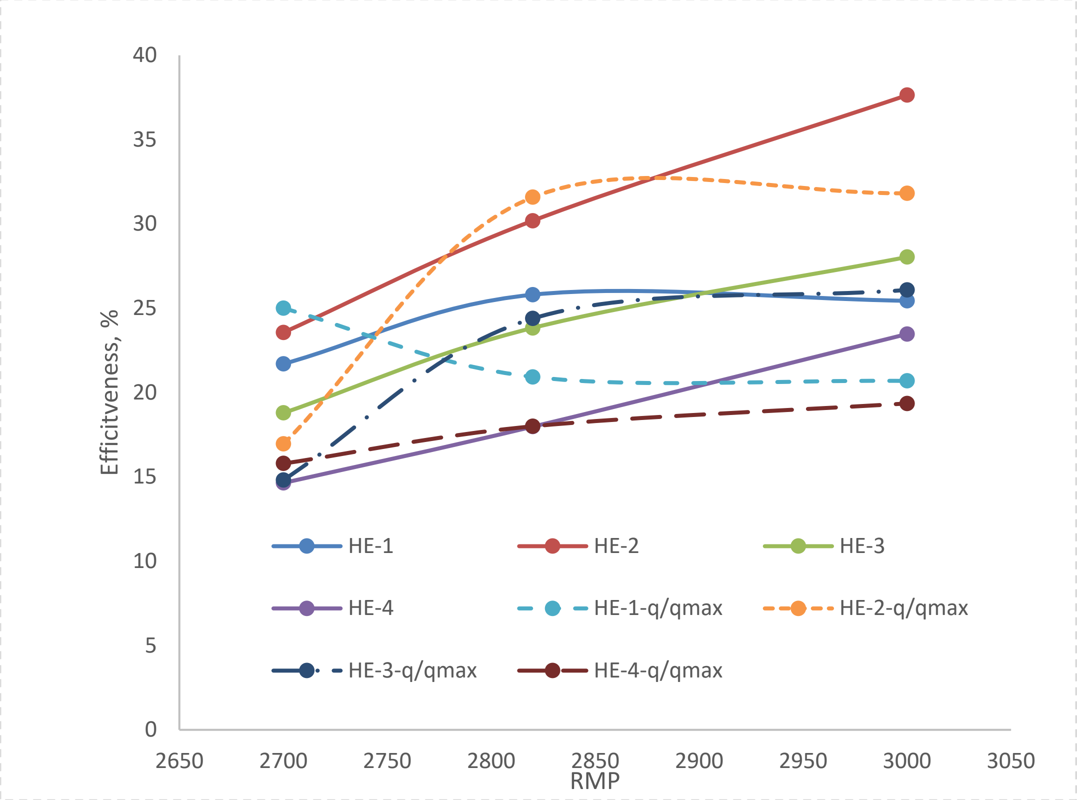

Fig. 8. Shows the effectiveness of each heat exchanger using ε-NTU model and q/qmax

On the other hand, Effectiveness, *ε, was calculated for each heat exchanger using ε-NTU model (eq.3).* Where NTU is number of transfer unit, C_{oil} is the specific heat of oil and C_{water} is the specific heat of water. The effectiveness is calculated from ε-NTU higher than the effectiveness calculated from q/qmax equation. This is due to the effect of the surface area of heat exchanger and overall heat transfer coefficient as shown in Figure 9, the HE-2 has the lowest U, on the other hand HE-1 has the highest overall heat transfer coefficient. Figure 8 shows the calculated effectiveness using equations 2 and 3. At 3000 RPM, table 2 shows the comparison between the two equations, it is observed that using ε-NTU gives higher efficiency than using q/qmax. Overall heat transfer coefficient is inversely proportional with log mean temperature difference (LMTD), therefore when the LMTD increases the heat transfer rate increases. LMTD was the highest for HE-2.

$$\epsilon_{cal} = \frac{1-[exp-NTU\left[1+\frac{C_{OIL}}{C_{WATER}}\right]]}{1+\frac{C_{OIL}}{C_{WATER}}} \tag{3}$$

$$\text{Where } NTU = \frac{UA}{C_{OIL}} \tag{4}$$

Table 2. shows the comparison between calculated effectiveness (eq. 3) and from eq.2 at RPM = 3000

Heat exchanger	Effectiveness % (ε-NTU)	Effectiveness % (q/qmax)
HE-1	26	21
HE-2	38	32
HE-3	28	26
HE-4	24	19

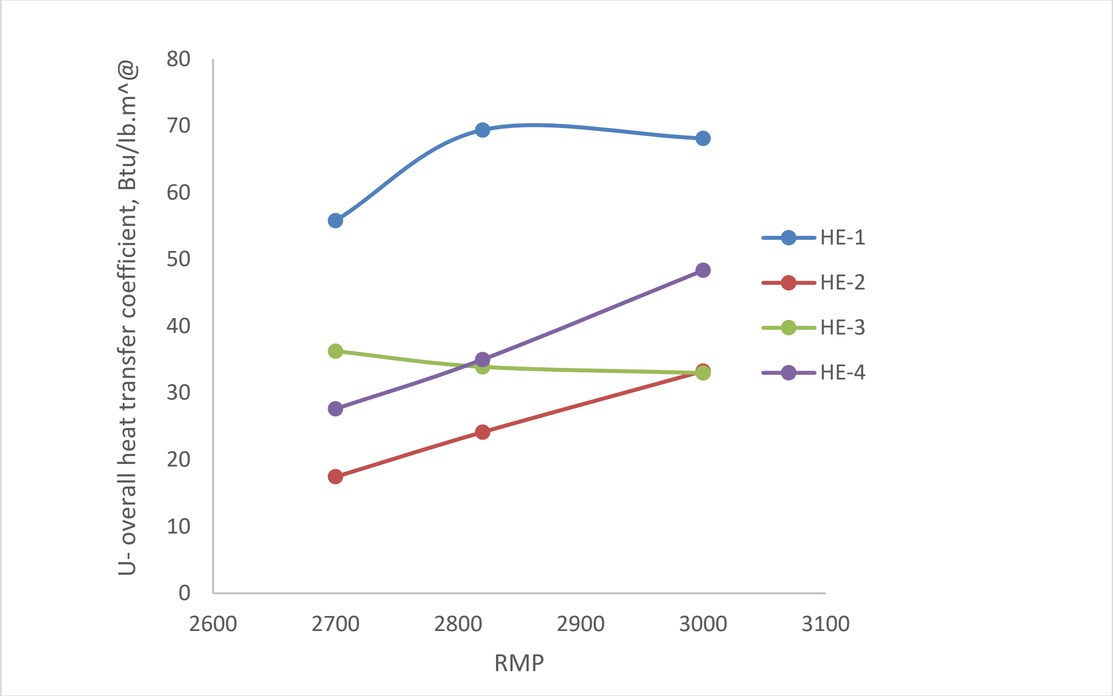

Fig. 9. shows the U-overall heat transfer coefficient vs. RMP

4. Conclusion

The performance of different designs of heat exchangers has been investigated experimentally using The Ford turbocharged diesel engine-generator by analyzing heat transfer rate, overall heat transfer coefficient and effectiveness. The results indicated that the heat transfer rate, effectiveness, overall heat transfer rate increased with increasing the diesel engine RPM. As the mass flowrate was constant, the heat exchanger (HE-2) has the highest effectiveness and heat transfer rate, however it has the lowest overall heat transfer coefficient. At 300 RPM, the effectiveness was 38% for HE-2, however the effectiveness was the lowest for HE-4. It is concluded that the surface area of heat exchanger, shape and location of the fins affects on the effectiveness of heat exchanger on the diesel generator.

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